Case Study on Coastal Wetlands and Eutrophication:

Gordon Pass, The Gulf Coast

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This case study investigates how remote sensing can be used to analyze the differences between coastal wetlands versus urban coastal features and their impact on eutrophication.

Remote sensing is a valuable tool that can help provide critical information from above, whereas ground measurements are limited to how many samples and measurements can be taken at one time. Remote sensing has the benefit of being able to take a snapshot from space that can then be analyzed. An example in scientific practice where remote sensing can be used is by evaluating coastal wetlands and their response to eutrophication. Eutrophication occurs when the environment becomes enriched with nutrients, increasing the amount of plant and algae growth to estuaries and coastal waters.[1] According to NOAA, 65% of the estuaries and coastal waters in the contiguous U.S. that have been studied by researchers are moderately to severely degraded by excessive nutrient inputs.

Most algae support healthy ecosystems by forming the base of the food web and producing oxygen. However, some algal species can harm humans, other animals, and the environment when they grow in excess. Harmful algal blooms (HABs) damage the environment because they replace vital food sources, clog fish gills, shade seagrass, or contribute to low oxygen dead-zones when they degrade. Some HAB species produce potent chemicals called toxins that can persist in the water and enter the food chain. These toxins can also lead to health problems in humans and animals. Therefore, it is important to have a better understanding of which HAB species are present in the water and the various processes that contribute to their growth and spread.[2]

The Gulf of Mexico is one area in the United States that is routinely impacted by HABs. There are over 70 HAB species that occur in the Gulf of Mexico. The most widespread however is the red tide organism – *Karenia brevis* – which is an ongoing threat to human and environmental health along the coast of Florida, and sometimes Texas and Mexico. *K. brevis* produces brevetoxins and can accumulate in shellfish, and as result of consumption lead to neurotoxic shellfish poisoning in humans. Wave action breaks open *K. brevis* cells that releases these toxins into the air leading to respiratory issues.[3]

While there is no uniform HAB monitoring or management program throughout the Gulf of Mexico, many targeted research programs have unique collaborations and provide ongoing data collection. The Florida Fish and Wildlife Commission and the University of South Florida College of Marine Science is one such collaboration that has contributed to the success of monitoring and

[1] US Department of Commerce, “What Is Eutrophication?”
[2] Corcoran et al., “A Primer on Gulf of Mexico - Harmful Algal Blooms.”
[3] Corcoran et al.

management of *K. brevis*. Together, the scientific team collects samples by boat, deploys underwater vehicles to map blooms, uses satellite images to measure bloom extent and distribution, and produces short-term forecasts of bloom movement. This information is available through NOAA web sites.

To establish the ideal site for this case study, NOAA's HABSOS (Harmful Algal Blooms Observing System) was helpful in determining which region along the southwestern coast of Florida was most impacted by red tide events. HABSOS identifies locations where in-situ samples were collected and counts the number of *K. brevis* cells. High reported values (>50,000 cells/L) are an indication of possible remote sensing detection, while even higher values (>100,000 cells/L) are an indication of possible fish kills. 2018 and 2019 had extremely high detection values along the coast, just above the Everglades, indicating red tides, which makes for a suitable study site to show the effects on eutrophication from varying coastal features. See Figure 1 and Figure 2 below. Historical records also indicate that *K. brevis* is the most common HAB to bloom along the southwestern coast and therefore is a strong signal during high chlorophyll measurements.

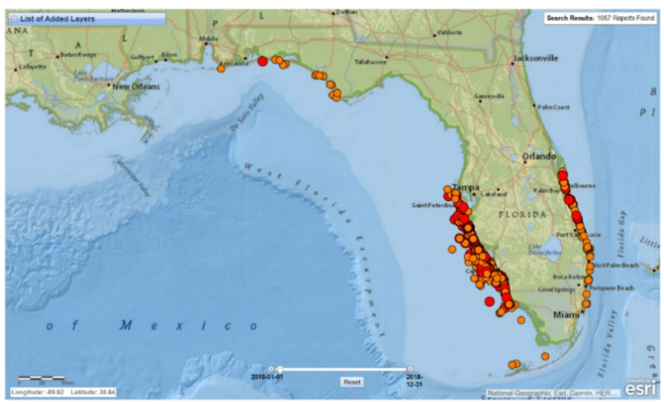


Figure 1: *High cell count of K. brevis (2018)*

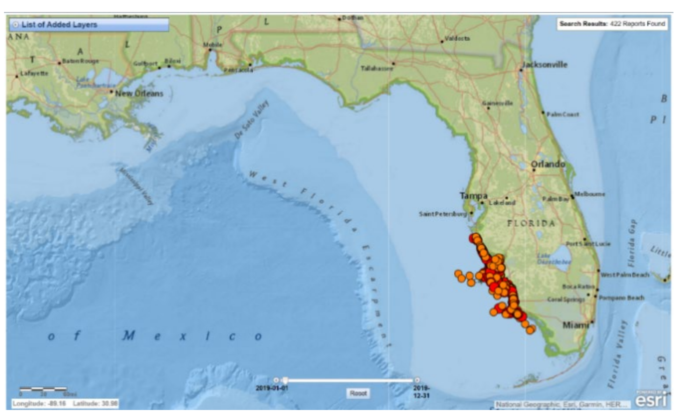


Figure 2*: High cell count of K. brevis (2019)*

The area especially attractive to study impact from coastal features is at the separation between the Everglades National Park and Naples, FL, just north of Marco Island.

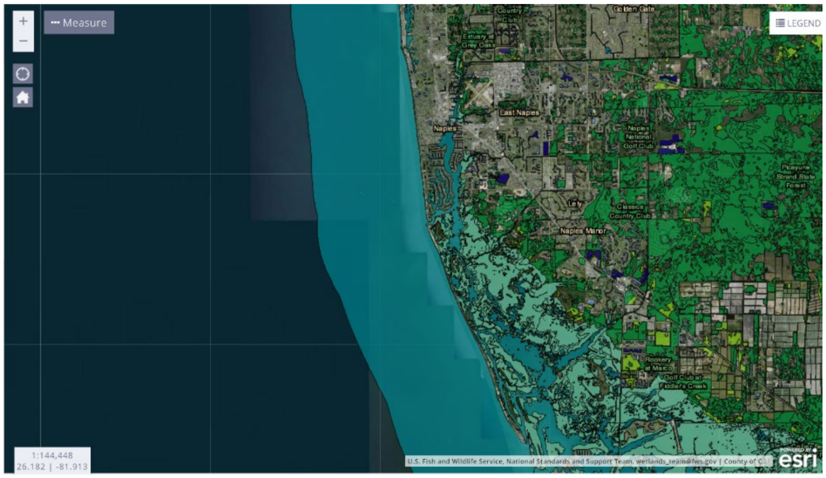


Figure 3: *Gulf of Mexico off the coast of Naples, Florida.*
(Source: National Wetlands Inventory)

The differences in the two coastal features are made obvious in Figure 3 (left) between the built, urban, and impervious features in Naples versus the dense estuarine wetlands to the south. The separation between the two types of features is a narrow bay, known as Gordon Pass, where Naples Bay meets the Gulf of Mexico. However, both regions are urbanized inland and, therefore, using remote sensing off the coast will provide a better analysis on how well the coastal wetland acts as a nutrient sink, primary source, or whether no observed differences are found between coastal features on eutrophication.

The following diagram in Figure 4 shows boundary areas for “A”, “B”, and “C”, selected to act as sites in the case study for data analysis. Each region is a 4 km x 4 km square area to correspond to the MODIS-Aqua chlorophyll concentration spatial resolution (4 km) that was gathered from NASA’s online Giavanni EarthData. I believe this is a suitable distance away from the coast to measure eutrophication from chlorophyll concentrations without being influenced by low coastal CDOM dynamics.

Each of the regions fall between two longitudes -81.83 W and -81.87 W and separated by a length of 4 km. “A” corresponds to the off-shore urban environment conditions, while “C” represents the off-shore wetland conditions. “B” acts as a control site, an area between the two coastal features, where Gordon Pass is situated.

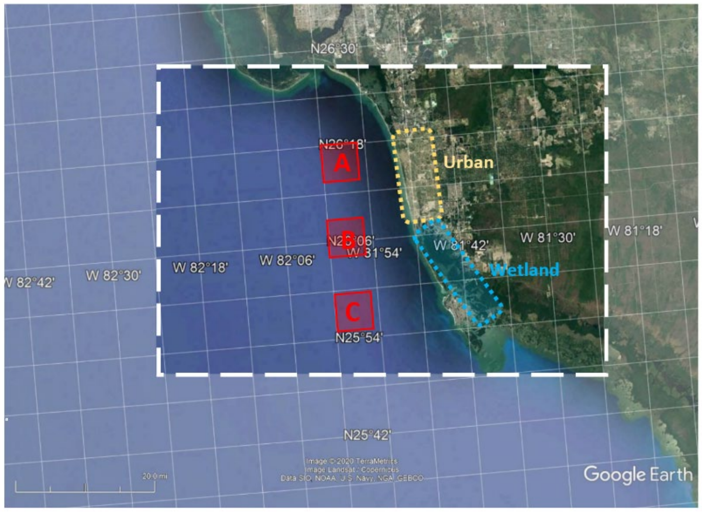


Figure 4: *Testing site with study regions A, B, and C. (Google Earth)*

The following Figures 5-7 are the MODIS-Aqua, 4km, 8-daily data for each of the regions described above and shown in Figure 4 for a time-series for 15 years between 2005-2020.

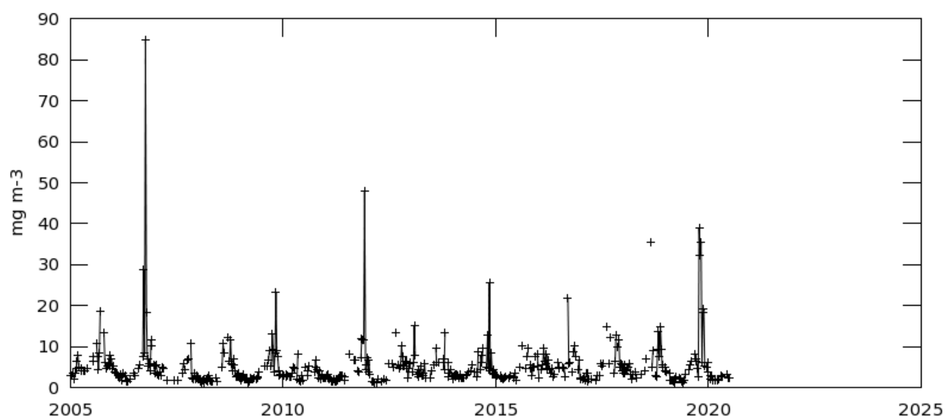


Figure 5: North of Gordon Pass ("A"). Time Series, Area-Averaged of Chlorophyll a concentration 8-daily, 4 km [MODIS-Aqua MODISA_L3m_CHL_8d_4km v2018] mg m-3 over 2005-01-01 – 2020-07-27, Region 81.87W, 26.16N, 81.83W, 26.2N

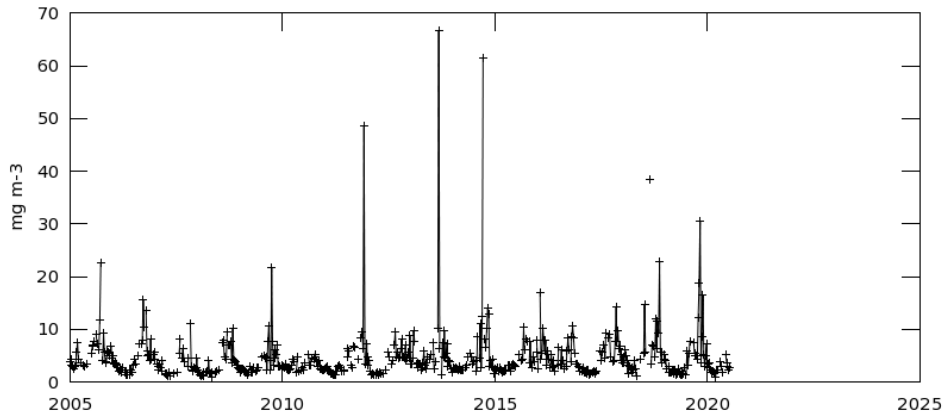


Figure 6: Gordon Pass ("B"). Time Series, Area-Averaged of Chlorophyll a concentration 8-daily, 4 km [MODIS-Aqua MODISA_L3m_CHL_8d_4km v2018] mg m-3 over 2005-01-01 – 2020-07-27, Region 81.87W, 26.08N, 81.83W, 26.12N

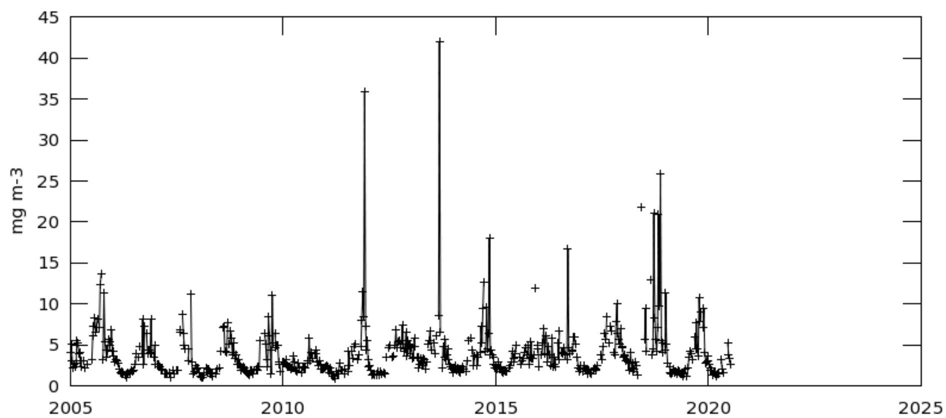


Figure 7: South of Gordon Pass ("C"). Time Series, Area-Averaged of Chlorophyll a concentration 8-daily, 4 km [MODIS-Aqua MODISA_L3m_CHL_8d_4km v2018] mg m-3 over 2005-01-01 – 2020-07-27, Region 81.87W, 26N, 81.83W, 26.04N

From the figures above there is a clear indication of seasonality by an obvious increase in chlorophyll measured off the coast typically recurring during the fall months. The decreasing scale on the y-axes of the graphs also indicate the rate of chlorophyll growth in the various areas. North of Gordon Pass shows less spikes than the other graphs, but when there is a measured spike it easily surpasses 40 mg/m^3, whereas Gordon Pass and South of Gordon Pass areas experience spikes at different times than the North, especially during the 2013 and 2014 seasons. Note how the scale in the South figure is half that of the North figure.

To better analyze these various datasets, I overlaid the time series in an excel spreadsheet to see how the various years differed when viewed on the same scale. See Figure 8 below for a visual of the overlying data for years 2014-2020.

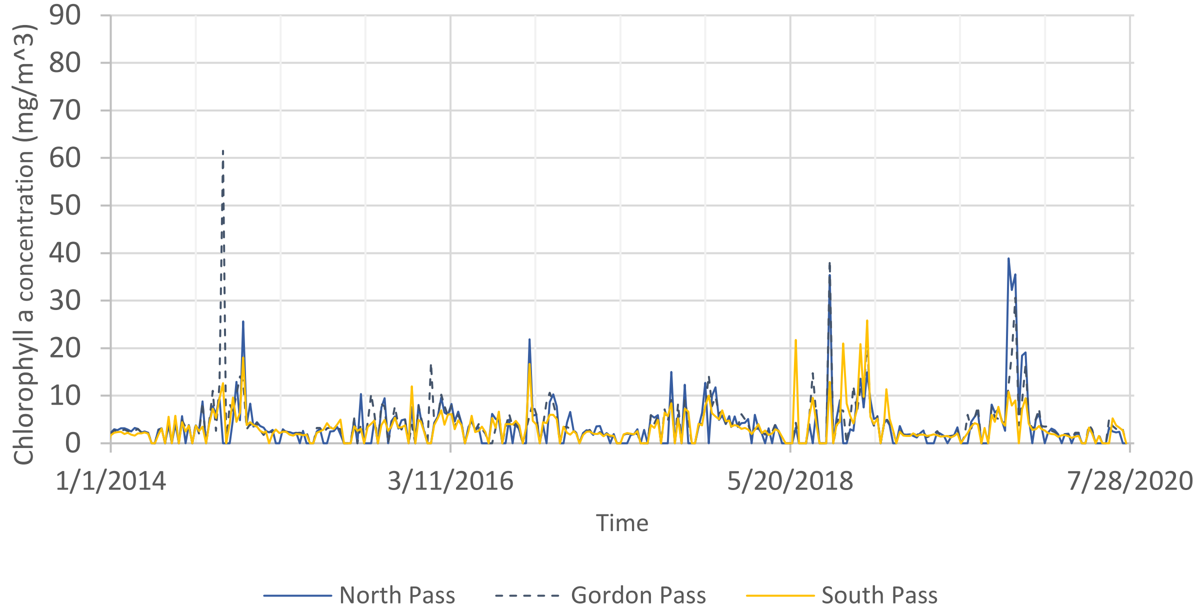


Figure 8: *Time-series overlay for years 2014-2020*

From the overlay 8-daily time-series data above, there seem to be uniform similarities between the various years in terms of seasonality and between region, but there are obvious outliers, for example the significantly higher rate measured at Gordon Pass in September 2014 (>60mg/m3). Also, there seem to be large gaps in the peaks during the past two seasons, 2018 and 2019, showing a much larger peak in chlorophyll in the North than in the South. For these reasons, I investigated the 2014 and 2019 seasons using Landsat8 imagery.

Landsat 8 imagery was obtained from the USGS Earth Explorer website. The following figure shows how the Landsat 8 imagery from October and November 2019 was processed by Acolite, which accounts for atmospheric correction.

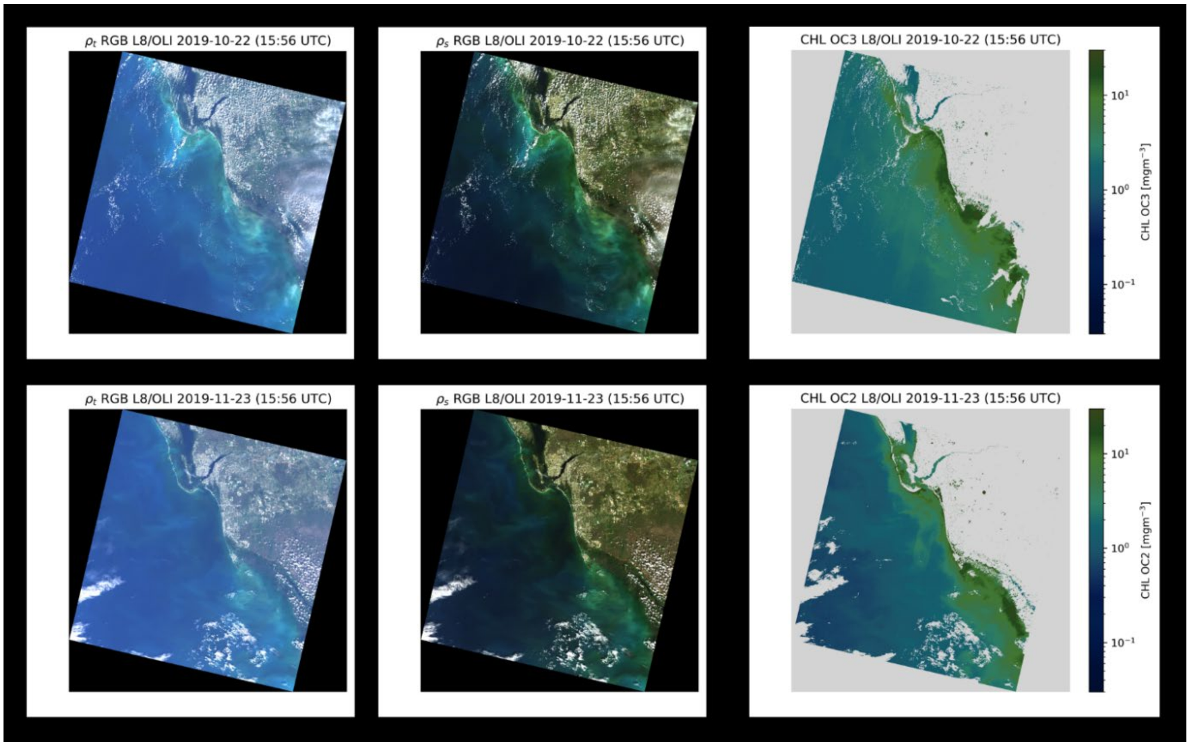


Figure 9: *Acolite chlorophyll corrections from Landsat 8 imagery taken on 2019-10-22 and 2019-11-23.*

Landsat 8 imagery is incredibly useful such that it can be processed through the Acolite atmospheric correction software and output a much higher resolution (30 m) than MODIS-Aqua (4 km). See Figure 10 for how these corrected datasets for these years were further evaluated in SeaDAS. Each image was taken on a different day. The colorbars for each image have the same scale in chlorophyll to emphasize the difference between a highly eutrophic season (2019) and one that was not so eutrophic (2014). Blooms can be easily identifiable from the “dendritic” eddies that jut out from the furthest extents of the high chlorophyll concentration. Pins are marked on the corners for each region designating North (blue pins), Gordon Pass (yellow), and South (red). The pins were imported into each map in SeaDAS to allow for easier transcribing of the chlorophyll concentration in each of the study boundaries. Data for each of the points is contained in Table 1.

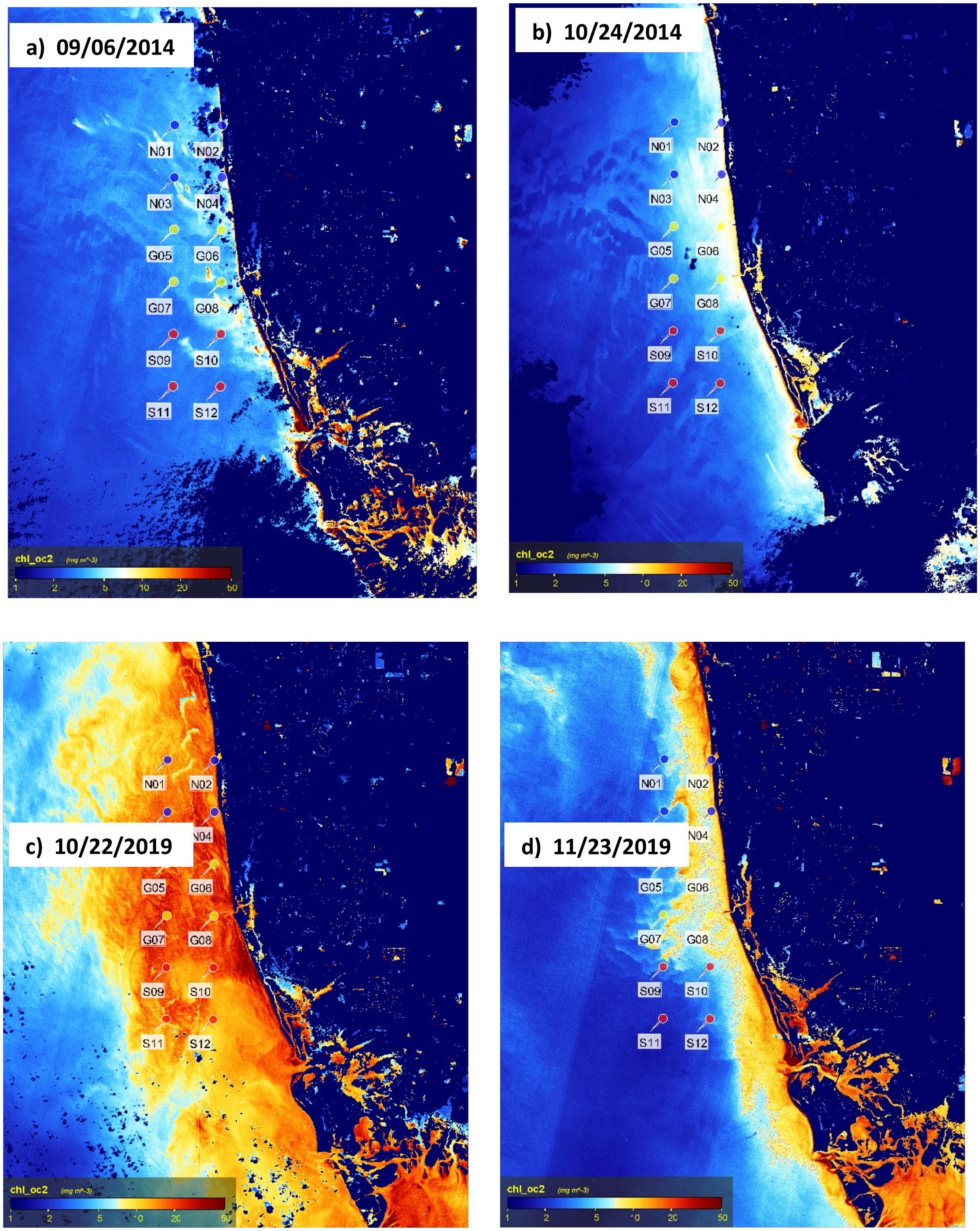
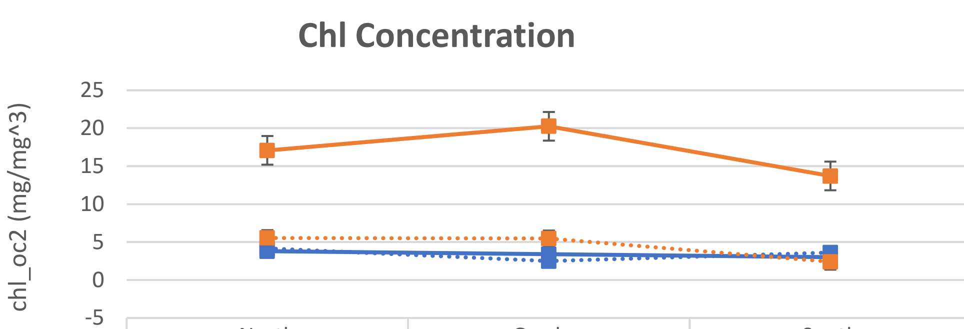


***Figure 10: Landsat 8 imagery**. **a)** 9/6/2014, **b)** 10/24/2014, **c)** 10/22/2019, and **d)** 11/23/2019.*

Table 1: *Landsat 8 chlorophyll concentrations (mg/m3) taken from SeaDAS. The averages for each region are at the bottom.*

ID	Lon	Lat	9/6/2014	10/24/2014	10/22/2019	11/23/2019
N01	-81.87	26.20	5.09	4.62	13.05	2.77
N02	-81.83	26.20	3.21	3.50	14.90	8.51
N03	-81.87	26.16	3.10	5.76	19.69	3.69
N04	-81.83	26.16	NaN	2.81	20.71	7.19
G05	-81.87	26.12	3.46	3.16	17.36	3.39
G06	-81.83	26.12	3.37	1.87	17.17	6.59
G07	-81.87	26.08	3.42	3.03	22.49	5.79
G08	-81.83	26.08	3.30	1.92	24.00	6.17
S09	-81.87	26.04	2.86	4.11	20.04	2.08
S10	-81.83	26.04	3.34	5.27	12.79	3.59
S11	-81.87	26.00	3.06	2.61	11.73	1.78
S12	-81.83	26.00	2.79	2.53	10.29	2.17
	North		3.80	4.17	17.09	5.54
	Gordon Pass		3.39	2.50	20.26	5.48
	South		3.01	3.63	13.72	2.40



	North	Gordon	South
9/6/2014	3.80	3.39	3.01
10/24/2014	4.17	2.50	3.63
10/22/2019	17.09	20.26	13.72
11/23/2019	5.54	5.48	2.40

Figure 11: *Average chlorophyll concentrations taken from SeaDAS.*

The following figure, Figure 12, shows the anomaly data for each region. Anomalies were calculated to be the difference between the seasonal chlorophyll concentration for 2014 and 2019 and the 15-year average baseline chlorophyll concentration.

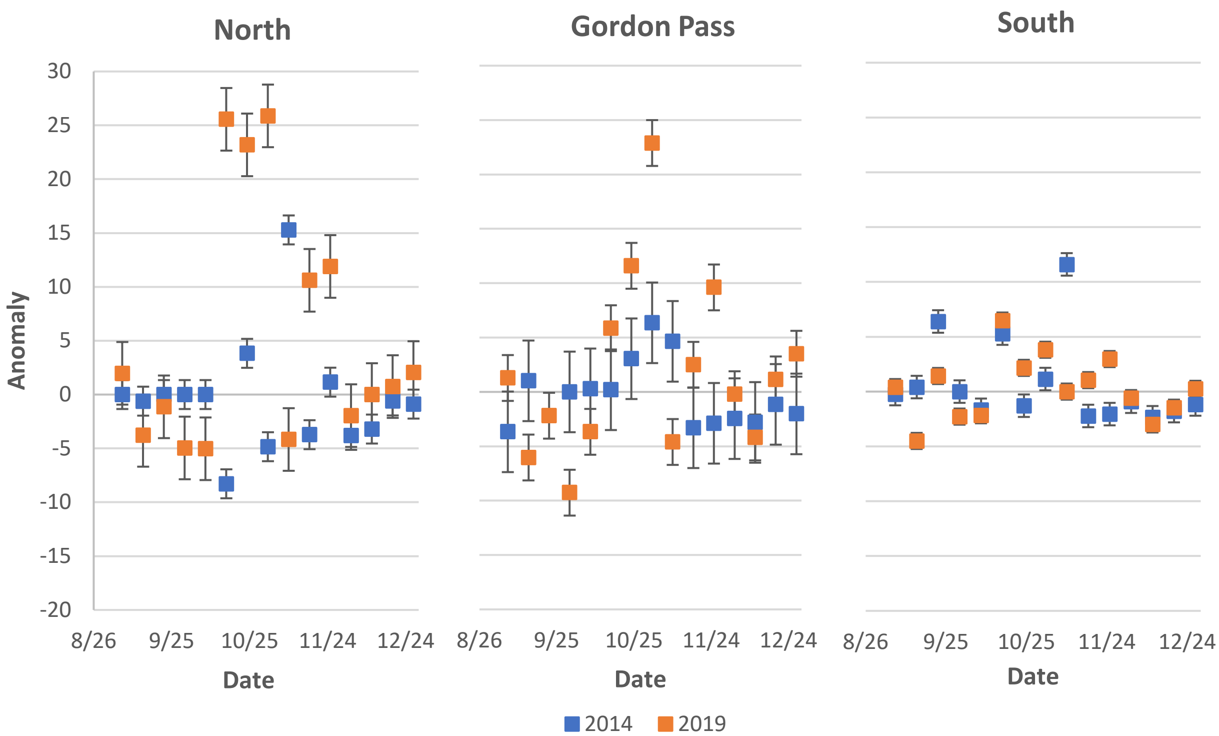


Figure 12: *Anomaly data for each region of interest (September-December).*

The average chlorophyll concentrations plotted in Figure 11 show that the North has an overall 16% increase in average chlorophyll concentration comparatively to Gordon Pass, while the south has an average 14% decrease in average chlorophyll concentration when compared to Gordon Pass.

The anomaly data in Figure 12 supports the same trend, showing that the North region of Gordon Pass has a greater number and higher anomalies during the 2019 red tide season when compared to both the South and at Gordon Pass. The same cannot be said about the 2014 season, and it seems that coastal wetlands do not play as significant of a role in minor chlorophyll concentrations as they perform during extreme chlorophyll concentrations, such as with red tide events.

The following figure shows the Hovmoller (longitude-average) of chlorophyll concentration using monthly MODIS-Aqua data between 2018 and 2020. The patterns that fluctuate between blue and orange, indicate the seasons of low to high chlorophyll concentration. The bright orange-yellow marks the peak in red tide HAB formation during both seasons. This is consistent with the previous figures, 8-daily MODIS-Aqua (Figures 5-7), and the overlay in Excel (Figure 8). The white areas are locations where no data could be processed, perhaps due to cloud cover or other weather-related reasons.

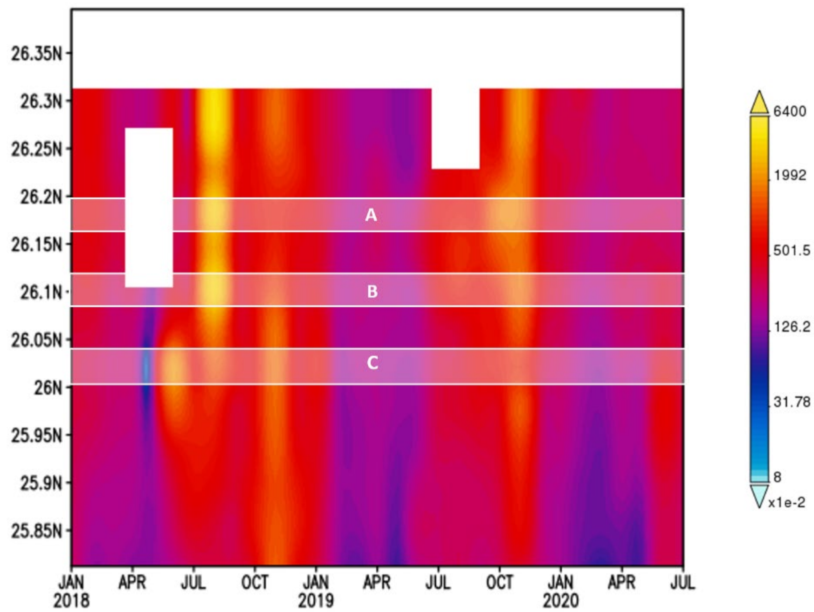


Figure 13: *Hovmoller, Longitude-Averaged of Chlorophyll a concentration monthly 4 km [MODIS-Aqua MODISA_L3m_CHL_v2018] mg m*$^{-3}$

The areas that are faded in Figure 13 are where the study boundaries are located. Clearly, from glancing at the Hovmoller plot there seems to be greater concentration of chlorophyll in the north ("A") than the south ("C"). Also, from this graph, there appears to be HAB movement from north to south, interpreted from the high concentration in September 2018 in the north and then appearing mostly in the south the following month. To better understand the dynamics of these HABs, which appear in the region during red tide events, it would be beneficial to look at the prevalent winds and current vectors in the area. Figure 14 shows the current generated from the Ocean Circulation Group at the University of South Florida. The region of interest off the coast of Naples, FL seems to have currents which flow consistently southwesterly. However, September 2014 shows currents with a slight northwestern direction. Physical factors play a critical role. Large-scale currents can transport HAB species throughout the Gulf of Mexico, connecting the region. Currents and winds can also concentrate HAB species along fronts or bring them into coastal embayments.[4]

[4] Corcoran et al.

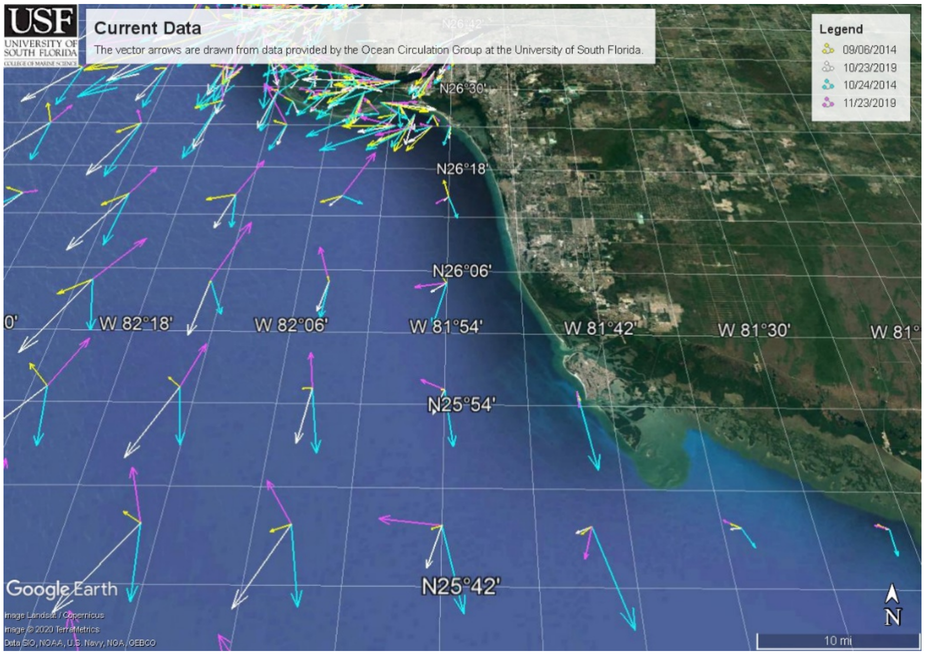


Figure 14: Current Data*. Vector arrows are drawn from data provided by the Ocean Circulation Group at the University of South Florida. Google Earth.*

This case study at the southwestern coast of Florida evaluates the extent of coastal wetlands on eutrophication when compared to nearby built-up environments. From both the Giavanni MODIS anomaly data and the Landsat8 imagery when inputted into SeaDAS, there seems to be statistical significance that coastal wetlands north of the Everglades were able to withstand and perhaps deter HAB growth and severity much more so than the urbanized area to the north. This is especially important today as the Everglades faces a major multi-billion-dollar restoration plan to construct a reservoir south of Lake Okeechobee to treat runoff rich in nutrients from the Everglades Agricultural Area (EAA).[5] The plan was developed primarily by the South Florida Water Management District (SFWMD) to reduce the number of damaging discharge events from Lake Okeechobee to the St. Lucie and Caloosahatchee rivers by 63% and increase the flow going south to the Everglades and Florida Bay by 76% from 0.26 to 0.46 m^3/year (160,000 to 370,000 acre-ft/year).[6] The design and construction of the reservoir proposes the expansion of 2630 ha (6500 acres) of treatment wetlands, only a 13% increase, to improve the water quality. The author of the report in Ecological Engineering states that this number is grossly insufficient to meet the need for treatment wetlands, and the figure should be closer to 40,000 ha (100,000 acres). This Everglades restoration project has accelerated recently due to

[5] Mitsch, "Restoring the Florida Everglades."
[6] Mitsch.

significant coastal pollution years in 2016, 2018, and 2019 – due primarily to the red tides caused by *K. brevis*. Additional research and investigations should be conducted near and around the Florida Everglades to better predict how a change in runoff from Lake Okeechobee will impact the coastal waters once the waters are diverted directly through the Everglades as opposed to being discharged to the rivers.

Furthermore, a deeper understanding of which geographies are more capable of withstanding greater loads can help us protect more vulnerable wetland areas and gain insight into the phytoremediation qualities of wetland species to aid in better restoration strategies.

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Final Questions

1) What is the one most important aspect of remote sensing that you learnt from doing your final project?

Through researching the conditions off the coast of Florida that arise during severe HAB events I realized that remote sensing made the most sense as a tool to use to evaluate the extent of the bloom, especially using Landsat 8 and its extremely high spatial resolution. Without the high resolution of Landsat, I would have not had a clear idea of what was happening off the Gulf Coast.

2) What was the biggest challenge in completing your final project?

I think coming up with a scale and boundaries for the various coastal feature offshore areas was the most challenging part of the project. I needed to find an area that was representative of the runoff from those coastal features that also was not impacted by being too close to the other boundaries or either too close to the coast or too far from the coast such that the data was not accurate to the conditions of the bloom.

3) What would you do different in terms of the question you asked and/or how you approached the project in retrospect (i.e. now that you have done it)?

I am pleased with the overall results of my remote sensing project, but I think if I would have looked at more than just one year for severe blooms and one without, there would be a better argument for coastal wetlands in this region having an ability to hold back nutrients from HAB growth. More data and more comparisons would help support my findings.

4) What was the most useful thing you learned in the course relevant to your final project - in terms of the question you posed and how you answered it?

I think learning about the different types of remote sensing and where exactly to access the data was critical for developing the skills to answer my own scientific hypothesis. I feel more confident in the resources that were taught throughout the course and am excited to continue to use them for similar questions and topics of interest in the future (now that I have NASA, USGS, and Copernicus account :).